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Host : Guest Chemistry of Diaza-18-crown-6: Selective Precipitation from Mixtures of Oligohydroxy Phenols and the Structures of Five Host : Guest Complexes

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Abstract. Diaza-18-crown-6 (1,4,10,13-tetraoxa-7,16-diaza-cyclo-octadecane) selectively precipitates as a 1,4-dihydroxybenzene-complex from a mixture of isomeric phenols and as a 2,6-dihydroxynapthalene-complex from mixtures of isomeric diols. These selective precipitations are discussed in terms of structure and solubility of the host-guest complexes and phenol acidity. The crystal structures of diaza-18-crown-6 with guests *p*-nitrophenol (2 : 1), 2,4-dinitroaniline (2 : 1), 5,5-diethylbarbituric acid (2 : 1), salicylaldoxime (2 : 1) and 1,4-dihydroxybut-2-yne (1 : 1) are reported.

Key words. Phenol, diol, diaza-18-crown-6, crystal structure.

Supplementary Data relating to this article are deposited with the British Library as Supplementary Publication No. SUP 82065 (74 pages).

1. Introduction

The interactions between crown macrocycles and uncharged organic host molecules have become of increasing interest during the past decade [1–3]. This is due partially to the interest in and importance of weak interactions in some biochemical processes. Crown compounds not only provide cavities, but also multiple electron donor centers that can act as binding sites for electrostatic dipole/dipole interactions and hydrogen bonding. Of particular interest is the multiplicity of these binding sites and their geometric arrangement. The stereochemical differences between host : guest complexes in the crystalline state and in solution are also of interest. X-ray analyses have shown that the complexation of neutral organic molecules by crowns is facilitated by the polarity or acidity of the HO—, HN—, or —CH donor groups.

18-Crown-6 is the most common polyether macrocycle for which the inclusion properties towards neutral guests have been studied in the solid state [2–5]. This system offers a variety of possible host : guest inclusions [6], and van Zon *et al.* [7] have carried out a detailed study of 18-crown-6 in different solvents and solvent mixtures to determine the efficiency and the selectivity of crystalline complex formation. In both respects, nitromethane, dimethyl carbonate, and dimethyl oxalate proved to be superior to acetonitrile which suggests these systems are better choices for the isolation of pure 18-crown-6 from

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crude reaction mixtures than the conventional method [8, 9]. They state the high efficiencies in complex isolation are due to solubility effects rather than to the formation of particularly stable complexes.

In general, complexes between diaza-18-crown-6 (1,4,10,13-tetraoxa-7,17-diazacyclooctadecane) and neutral organic molecules containing proton donors are stabilized by hydrogen bonds to the diaza nitrogen atoms. More recently, host : guest complexes of diaza-18-crown-6 with tropolone and 4-hydroxy-3-methoxybenzaldehyde as guests have been described [10]. They proved to be ionic complexes with a guest-to-host stoichiometry of 2 : 1. The diaza-18-crown-6 dications in the two solid state structures adopt different conformations. One of the conformers resembles that of free diaza-18-crown-6, whereas the other conformer has not been observed previously.

The present contribution is confined to the host:guest inclusion chemistry of diaza-18-crown-6. We report the formation of 1 : 1 and 1 : 2 host : guest complexes with a variety of oligohydroxy aromatics and illustrate the use of selective complex formation by the precipitation of specific guest molecules from mixtures. We also report the structures of five new complexes. In particular, we report two structures which pack poorly in the solid state and may give a glimpse of the interactions in solution.

2. Experimental

Host : guest complexes between compounds **1** through **16** and diaza-18-crown-6 were investigated.

2.1. PREPARATION OF COMPLEXES OF 1, 2, 3, 7, 8, 9, 14, 15, AND 16 WITH DIAZA-18-CROWN-6

Diaza-18-crown-6, 66.5 mg (0.25 mmol), and 0.5 mmol of the guest compound were refluxed in 0.5 mL or 1.0 mL of ethylacetate for 1 hour. The complexes precipitated either

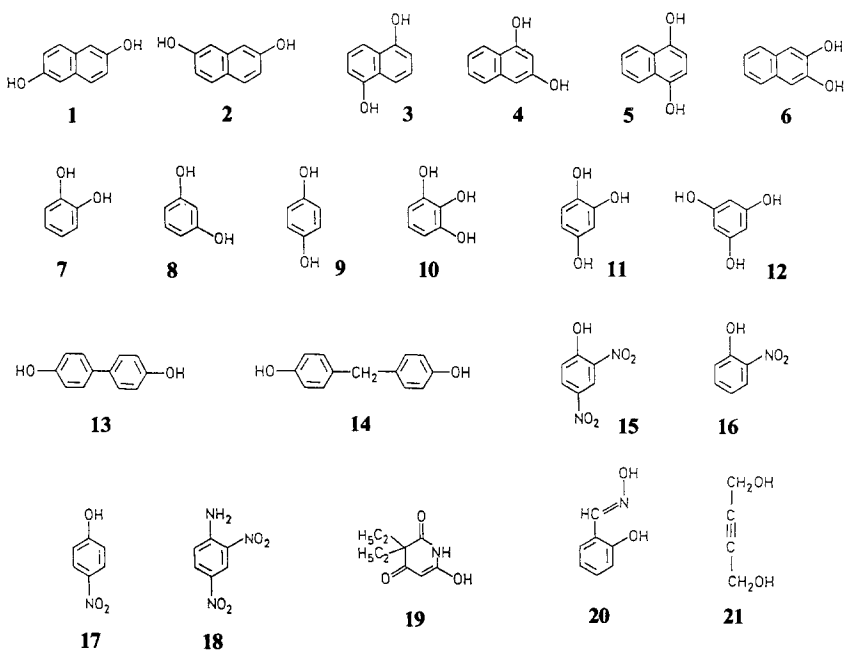

Table I. Complexation of the guest compounds **1**, **2**, **3**, **7**, **8**, **9**, **14**, **15** and **16** with diaza-18-crown-6

Guest compound	Complex stoichiometry (diaza-18-crown-6 : guest)	Yield	M.P. °C	Formula	Mol. weight	Calculated			Found		
						C	H	N	C	H	N
1	1 : 1	94 mg (89%)	161–165	$C_{22}H_{34}N_2O_6$	422.52	62.53	8.11	6.63	62.75	7.98	6.43
2	2 : 3	77 mg (47%)	125–128	$C_{54}H_{76}N_4O_{14}$	1005.21	64.52	7.62	5.58	64.86	7.74	5.63
3	1 : 1	48 mg (45.7%)	190–199	$C_{22}H_{34}N_2O_6$	422.52	62.53	8.12	6.61	62.31	7.94	6.60
7	1 : 2	56 mg (46.7%)	101–103	$C_{24}H_{38}N_2O_8$	482.57	59.73	7.94	5.81	59.94	7.94	5.66
8	1 : 1	43 mg (46.3%)	111–114	$C_{18}H_{32}N_2O_6$	372.46	58.04	8.66	7.52	58.31	8.54	7.17
9	1 : 1	75 mg (80.7%)	152–157	$C_{18}H_{32}N_2O_6$	372.46	58.04	8.66	7.52	58.09	8.66	7.49
14	1 : 2	125 mg (38%)	139–145	$C_{38}H_{50}N_2O_8$	662.83	68.85	7.61	4.23	69.29	7.42	4.44
15	1 : 2	139 mg (88.5%)	230–231	$C_{24}H_{34}N_6O_{14}$	630.55	45.71	5.44	13.33	45.98	5.44	13.39
16	1 : 2	92 mg (68.7%)	105–111	$C_{24}H_{36}N_4O_{10}$	540.57	53.32	6.71	10.37	53.18	6.89	10.15

from the boiling solution, after cooling to room temperature or cooling at 4°C. After filtration the crystals were washed with cold ethylacetate and dried in vacuum. The data are given in Table I.

The above conditions did not produce precipitates with the phenolic compounds **4**, **5**, **6**, **10**, **11**, **12** and **13**.

2.2. SEPARATION OF SPECIFIC HOST : GUEST COMPLEXES FROM PHENOLIC GUEST MIXTURES BY SELECTIVE PRECIPITATION USING DIAZA-18-CROWN-6

Diaza-18-crown-6, 0.25 mmol, and 0.5 mmol of each guest phenol in the mixture were refluxed in 0.75 mL ethylacetate for 1 hour and then cooled to room temperature. The complexes either precipitated during heating or upon cooling to 4°C. Identification was carried out by ^{1}H NMR and elemental analysis. The results of the selective precipitations are given in Table II. No recrystallization of samples was necessary.

Table II. Selective precipitation of specific guest molecules from mixtures using diaza-18-crown-6

Guest mixture	Guest precipitated*	Yield of precipitation* [mg] [%]	m.p. [°C]
0.5 mmol (**1**) 0.5 mmol (**2**)	**1**	41 (70.69%)	161–165
0.5 mmol (**1**) 0.5 mmol (**4**)	**1**	28 (48.28%)	161–166
0.5 mmol (**1**) 0.5 mmol (**5**)	**1**	26 (44.83%)	161–165
0.5 mmol (**1**) 0.5 mmol (**6**)	**1**	16 (27.59%)	161–166
0.5 mmol (**2**) 0.5 mmol (**3**)	**3**	14 (24.14%)	125–127
0.5 mmol (**2**) 0.5 mmol (**9**)	**9**	16 (43.26%)	152–157
0.5 mmol (**7**) 0.5 mmol (**9**)	**9**	26 (70.27%)	152–157
0.5 mmol (**8**) 0.5 mmol (**9**)	**9**	23 (64.87%)	152–157
0.5 mmol (**8**) 0.5 mmol (**7**) 0.5 mmol (**9**)	**9**	20 (54.05%)	152–157
0.5 mmol (**15**) 0.5 mmol (**16**)	**15**	57 (92%)	230–232

* Together with diaza-18-crown-6.

2.3. X-RAY STRUCTURAL ANALYSIS

All X-ray data were collected on a Nicolet R3M/μ update of a $P2_1$ diffractometer. Data were collected either by $\theta : 2\theta$ or Wyckoff (2θ fixed, ω varied) modes using graphite monochromated radiation. In general, lattice parameters were obtained from a least-squares fit of 25 high angle reflections; however, in some cases crystal quality and decomposition imposed limits. A ψ-scan empirical absorption correction was applied to all data. The structures were solved by direct methods and refined by block-cascade least-squares procedures. In general, hydrogen atoms were located in difference maps and then allowed to ride on the attached atom. Some donor amine and hydroxyl hydrogen atoms were refined. The isotropic thermal parameters of the riding hydrogen atoms were arbitrarily fixed or were refined as a single value. The function minimized was $\Sigma\, w(|F_o| - |F_c|)^2$ where $w = [\sigma^2(F_o) + gF_o^2]^{-1}$ and g is optimized during the refinement. All computer programs were supplied by Nicolet [11] for Desktop 30 Microeclipse and Nova 4/C configuration with atomic scattering factors and anomalous dispersion corrections from *International Tables for X-ray Crystallography* [12]. Anisotropic thermal parameters, hydrogen atom positional parameters, complete bond length and valence angle tables and structure factor tables have been deposited. Crystal and molecular data are given in Table III.

2.4. COMPLEX **22** (2 : 1 *p*-NITROPHENOL (**17**) : DIAZA-18-CROWN-6)

Diaza-18-crown-6, 65.6 mg (0.25 mmol), and 69.6 mg (0.5 mmol) *p*-nitrophenol in 1 mL ethylacetate were refluxed with magnetic stirring for 1 h. After hot filtration the solution was allowed to crystallize by standing at room temperature; yield 86 mg (64%), m.p. 114-117°C. Calcd. for $C_{24}H_{36}N_4O_{10}$: C 53.33, H 6.71, N 10.37; Found: C 53.22, H 6.93, N 10.95. A poor quality crystal of dimensions $0.25 \times 0.30 \times 0.40$ mm was used for all X-ray studies. The hydroxyl and amine hydrogen atoms were refined. The largest peaks in the final difference map were $+0.14$ and -0.12 eÅ^{-3}. Atomic positional parameters are given in Table IV and Figure 1 is a drawing of the molecule.

2.5. COMPLEX **23** (2 : 1 2,4-DINITROANILINE (**18**) : DIAZA-18-CROWN-6)

The complex was prepared by the procedure described for **22**; yield 96 mg (61.5%), m.p. 131–134°C. Calcd. for $C_{24}H_{36}N_8O_{12}$: C 45.86, H 5.77, N 17.83; Found C 45.59, H 5.74, N 17.64. A crystal of dimensions $0.25 \times 0.28 \times 0.38$ mm was used for all X-ray studies. Positional parameters of amine hydrogen atoms were refined. The largest peaks in the final difference map were $+0.15$ and -0.14 eÅ^{-3}. Atomic positional parameters are given in Table V and Figure 2 is a drawing of the molecule.

2.6. COMPLEX **24** (2 : 1) 5,5-DIETHYLBARBITURIC ACID (**19**) : DIAZA-18-CROWN-6)

The complex was prepared by the procedure described for **22**; yield 42 mg (37.8%), m.p. 97–105°C. Calcd. for $C_{28}H_{50}N_6O_{10}$: C 53.32, H 7.99, N 13.32; Found: C 53.63, H 8.21, N 12.87. A crystal of dimensions $0.4 \times 0.3 \times 0.6$ mm was used for all X-ray studies. Positional parameters of the hydrogen atom on the ring nitrogen were refined. The largest peaks in the final difference Fourier map were $+0.50$ and -0.35 eÅ^{-3}. Atomic positional parameters are given in Table VI and Figure 3 is a drawing of the molecule.

Table III. Crystal and molecular data for complexes **22–26**

22	**23**	**24**	**25**	**26**
$C_{12}H_{26}O_4N_2 \cdot 2C_6H_5NO_3$	$C_{12}H_{26}O_4H_2 \cdot 2C_6H_5N_3O_4$	$C_{12}H_{26}O_4N_2 \cdot 2C_8H_{12}N_2O_3$	$C_{12}H_{26}O_4N_2 \cdot 2C_7H_7NO_2$	$C_{12}H_{26}O_4N_2 \cdot C_4H_6O_2$
FW = 540.58	FW = 628.60	FW = 630.75	FW = 536.37	FW = 348.44
$P2_1/n$, Mo$K\alpha$ radiation	$P2_1/n$, Mo$K\alpha$ radiation	$P\bar{1}$, Cu$K\alpha$ radiation	$P2_1/c$, Mo$K\alpha$ radiation	$C2/m$ (Cm, $C2$), Mo$K\alpha$ radiation
$a = 10.115(8)$, $b = 13.961(8)$	$a = 11.533(2)$, $b = 7.654(2)$	$a = 9.563(3)$, $b = 12.748(4)$	$a = 9.569(3)$, $b = 5.596(2)$	$a = 7.917(7)$, $b = 14.418(10)$
$c = 10.404(9)$ Å, $\beta = 111.58(5)°$	$c = 17.755(3)$ Å, $\beta = 103.76(1)°$	$c = 7.745(2)$ Å, $\alpha = 118.03(2)$ $\beta = 91.12(2)$, $\gamma = 91.92(3)°$	$c = 27.954(9)$ Å, $\beta = 98.35(3)°$	$c = 8.764(7)$ Å, $\beta = 102.03(7)°$
$V = 1366(1)$ Å^3, $F(000) = 576$	$V = 1527.5(5)$ Å^3, $F(000) = 664$	$V = 832.3(4)$ Å^3, $F(000) = 340$	$V = 1481.0(8)$ Å^3, $F(000) = 552$	$V = 978(2)$ Å^3, $F(000) = 380$
$Z = 2$, $\mu = 0.96$ cm^{-1}	$Z = 2$, $\mu = 1.04$ cm^{-1}	$Z = 1$, $\mu = 7.59$ cm^{-1}	$Z = 2$, $\mu = 0.80$ cm^{-1}	$Z = 2$, $\mu = 0.84$ cm^{-1}
$d_c = 1.314$ g cm^{-3}	$d_c = 1.323$ g cm^{-3}	$d_c = 1.258$ g cm^{-3}	$d_c = 1.143$ g cm^{-3} ($d_o = 1.15$ g cm^{-3})	$d_c = 1.183$ g cm^{-3} ($d_o = 1.2$ g cm^{-3})
1794 reflections	2679 reflections	2286 reflections	1151 reflections	1471 reflections
$1356 \geqslant 2.5\sigma(I)$	$2050 \geqslant 2.5\sigma(I)$	$2230 \geqslant 2.5\sigma(I)$	$611 \geqslant 2.5\sigma(I)$	$504 \geqslant 2.5\sigma(I)$
$R = 0.0530$, $R_w = 0.0415$	$R = 0.0443$, $R_w = 0.0435$	$R = 0.0444$, $R_w = 0.0613$	$R = 0.0615$, $R_w = 0.0640$	$R = 0.0666$, $R_w = 0.0751$
$(\Delta/\sigma)_{max} = 0.038$, $S = 1.411$	$(\Delta/\sigma)_{max} = 0.09$, $S = 1.62$	$(\Delta/\sigma)_{max} = 0.18$, $S = 2.21$	$(\Delta/\sigma)_{max} = 0.014$, $S = 1.522$	$(\Delta/\sigma)_{max} = 0.03$, $S = 1.835$
$0 \leqslant h \leqslant 11$, $0 \leqslant k \leqslant 16$	$0 \leqslant h \leqslant 14$, $0 \leqslant k \leqslant 10$	$0 < h < 10$, $-13 \leqslant k \leqslant 13$	$0 \leqslant h \leqslant 12$, $0 \leqslant k \leqslant 7$	$0 \leqslant h \leqslant 9$, $0 \leqslant k \leqslant 16$
$-12 \leqslant l \leqslant 12$	$-22 \leqslant l \leqslant 22$	$-8 \leqslant l \leqslant 8$	$-34 \leqslant l \leqslant 34$	$-10 \leqslant l \leqslant 10$

Table IV. Atomic coordinates ($\times 10^4$) and isotropic thermal parameters ($Å^2 \times 10^3$) for complex **22**

	x	*y*	*z*	*U**
N(1)	3958(3)	5497(2)	−2834(2)	50(1)
C(2)	2957(3)	6305(2)	−3248(3)	54(1)
C(3)	3491(3)	7126(2)	−2271(3)	53(1)
O(4)	3593(2)	6839(1)	−928(2)	55(1)
C(5)	4422(3)	7495(2)	82(3)	63(1)
C(6)	4472(3)	7212(2)	1477(3)	60(1)
O(7)	5357(2)	6401(1)	1950(2)	53(1)
C(8)	5522(3)	6142(2)	3311(3)	59(1)
C(9)	6546(3)	5328(2)	3755(3)	59(1)
C(10)	7445(3)	6068(2)	−1228(3)	49(1)
C(11)	7387(3)	5261(2)	−484(3)	53(1)
C(12)	8449(3)	5083(2)	772(3)	51(1)
C(13)	9563(3)	5717(2)	1281(3)	46(1)
C(14)	9625(3)	6522(2)	553(3)	54(1)
C(15)	8560(3)	6703(2)	−688(3)	55(1)
O(16)	6460(2)	6266(2)	−2479(2)	68(1)
N(17)	10672(3)	5526(2)	2611(2)	66(1)
O(18)	11689(2)	6068(2)	3009(2)	87(1)
O(19)	10554(3)	4831(2)	3270(2)	103(1)

* Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor.

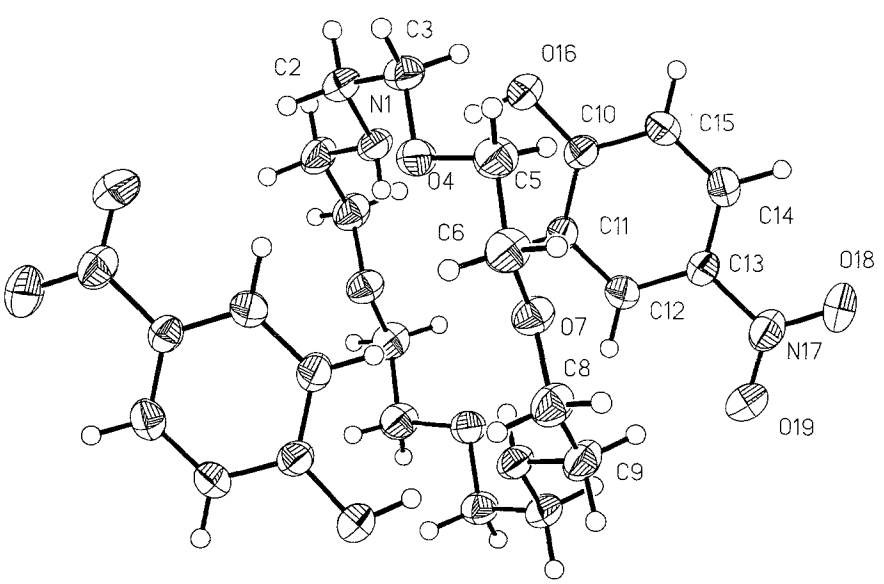

Fig. 1. Drawing of complex **22** with thermal ellipsoids drawn at the 35% probability level. H atoms are represented by spheres of arbitrary size.

Table V. Atomic coordinates ($\times 10^4$) and isotropic thermal parameters ($Å^2 \times 10^3$) for complex **23**

	x	*y*	*z*	*U**
N(1)	345(1)	−204(2)	6582(1)	57(1)
C(2)	1319(2)	874(3)	7020(1)	73(1)
C(3)	1317(2)	2639(3)	6673(1)	76(1)
O(4)	1597(1)	2481(2)	5942(1)	63(1)
C(5)	1646(2)	4135(3)	5582(1)	69(1)
C(6)	1776(2)	3874(3)	4781(1)	68(1)
O(7)	739(1)	3065(2)	4334(1)	60(1)
C(8)	726(2)	2955(3)	3531(1)	69(1)
C(9)	−377(2)	1994(3)	3134(1)	67(1)
C(10)	2750(1)	−1683(2)	4125(1)	47(1)
C(11)	2499(2)	−762(2)	4760(1)	59(1)
C(12)	3267(2)	−695(3)	5469(1)	60(1)
C(13)	4352(2)	−1574(2)	5593(1)	50(1)
C(14)	4657(1)	−2482(2)	5005(1)	48(1)
C(15)	3871(1)	−2539(2)	4281(1)	45(1)
N(10)	1949(1)	−1680(2)	3453(1)	64(1)
N(11)	4257(1)	−3522(2)	3686(1)	59(1)
O(16)	5266(1)	−4130(2)	3836(1)	79(1)
O(17)	3561(1)	−3733(2)	3053(1)	81(1)
N(13)	5176(2)	−1511(2)	6352(1)	65(1)
O(18)	6142(1)	−2240(2)	6445(1)	85(1)
O(19)	4869(2)	−721(3)	6869(1)	105(1)

* Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor.

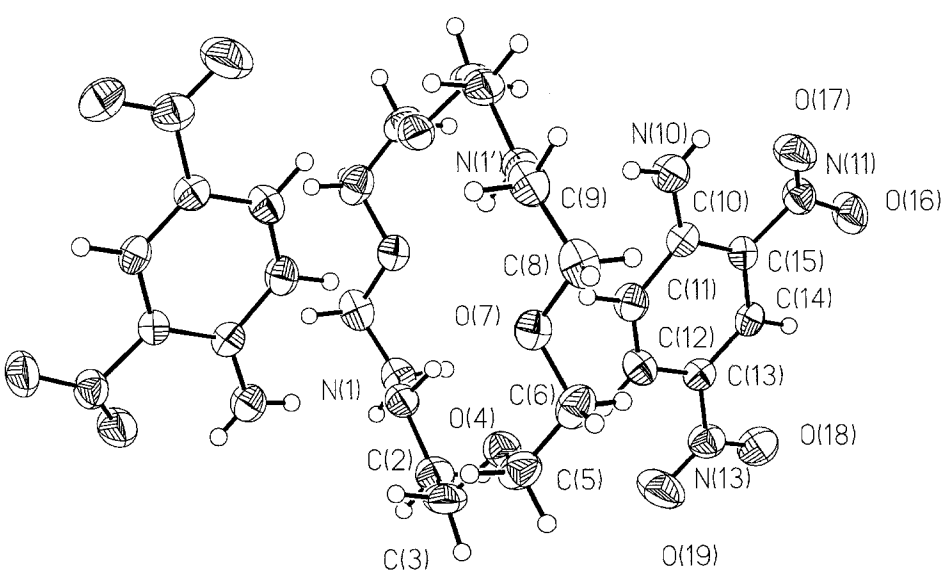

Fig. 2. Drawing of complex **23** with thermal ellipsoids drawn at the 35% probability level. H atoms are represented by spheres of arbitrary size.

Table VI. Atomic coordinates ($\times 10^4$) and isotropic thermal parameters (Å $\times 10^3$) for complex **24**

	x	*y*	*z*	*U**
N(1)	1718(1)	4749(1)	8030(2)	37(1)
C(2)	3127(2)	5372(2)	8568(3)	50(1)
C(3)	3349(2)	6134(2)	10739(3)	55(1)
O(4)	3335(1)	5388(1)	11622(2)	51(1)
C(5)	2257(2)	6012(2)	13700(3)	58(1)
C(6)	2247(2)	6746(2)	14662(3)	57(1)
O(7)	988(1)	6030(1)	14042(2)	48(1)
C(8)	−196(2)	6716(2)	14785(3)	49(1)
C(9)	−1486(2)	5913(2)	14144(2)	48(1)
N(10)	590(1)	1335(1)	9597(2)	40(1)
C(11)	1618(2)	564(1)	8748(2)	40(1)
C(12)	2823(2)	988(1)	7964(2)	41(1)
C(13)	2573(2)	2168(1)	7975(2)	40(1)
N(14)	1487(1)	2830(1)	8858(2)	40(1)
C(15)	519(2)	2457(1)	9701(2)	37(1)
O(16)	−480(1)	3042(1)	10568(2)	52(1)
O(17)	1568(1)	−424(1)	8659(2)	61(1)
O(18)	3427(1)	2508(1)	7131(2)	57(1)
C(19)	3111(2)	36(2)	5869(3)	52(1)
C(20)	1932(3)	−231(2)	4386(3)	69(1)
C(21)	4130(2)	1170(2)	9293(3)	63(1)
C(22)	4031(3)	2074(3)	11409(4)	94(1)

* Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor.

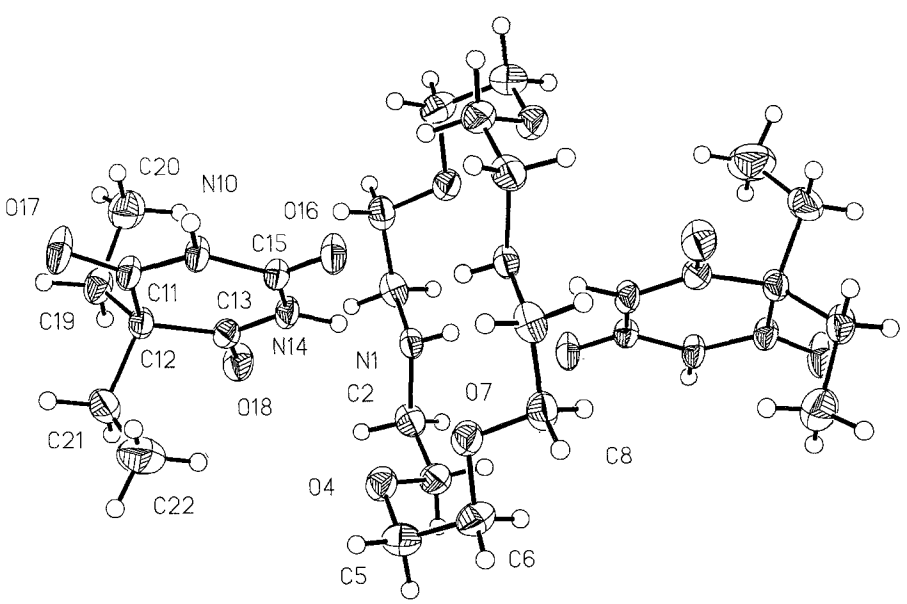

Fig. 3. Drawing of complex **24** with thermal ellipsoids drawn at the 35% probability level. H atoms are represented by spheres of arbitrary size.

2.7. COMPLEX **25** (2 : 1 SALICYLALDOXIME (**20**) : DIAZA-18-CROWN-6)

The complex was prepared by the procedure described for **22**; yield 13 mg (9.7%) m.p. 98–101°C. Calcd. for $C_{26}H_{40}N_4O_8$: C 58.17, H 7.52, N 10.44; Found C 58.42, H 7.31, N 10.24. A poor quality crystal of dimensions 0.4 × 0.3 × 0.7 mm was used for all X-ray studies. Positional parameters of the aldoxime hydrogen atom were refined. The phenolic hydrogen could not be located although low electron density (0.13 eÅ^{-3}) was found between the phenolic oxygen atom and the nitrogen atom of the oxide. This position did not refine satisfactorily. The largest peaks in the final difference map were +0.13 and −0.11 eÅ^{-3}. Atomic positional parameters are given in Table VII and Figure 4 is a drawing of the molecule.

2.8. COMPLEX **26** (1 : 1 1,4-DIHYDROXYBUT-2-YNE (**21**) : DIAZA-18-CROWN-6)

The complex was prepared by the procedure described for **22**; yield 66 mg (76.3%) m.p. 104–101°C. Calcd. for $C_{16}H_{32}N_2O_6$: C 55.13, H 9.26, N 8.04; Found: C 54.91, H 9.24, N 7.92. A very poor quality crystals of dimensions 0.2 × 0.15 × 0.3 mm was used for all X-ray studies. The reference reflections indicated about a 20% decrease in intensity during data collection. Space groups *C*2/*m*, *Cm* and *C*2 were consistent with systematic absences. *C*2/*m* and *Cm* refined to the same *R* value. *C*2/*m* was selected because most crown complexes exhibit centrosymmetric space groups and fewer parameters were required to achieve the lowest *R* value. Statistics cannot distinguish between structures differing by a small shift in atomic positional parameters. The unequivocal identification of space group is not essential to the elucidation of the molecular orientation. The largest peaks in the final difference map were +0.25 and −0.35 eÅ^{-3}. Atomic positional parameters are given in

Table VII. Atomic coordinates (× 10^4) and isotropic thermal parameters (Å^2 × 10^3) for complex **25**

	x	*y*	*z*	*U**
N(1)	−3208(9)	8414(8)	537(2)	50(5)
C(2)	−3995(12)	9986(11)	814(2)	117(8)
C(3)	−4863(11)	8577(11)	1114(2)	98(8)
O(4)	−5859(8)	7223(7)	802(1)	91(5)
C(5)	−6687(12)	5679(10)	1044(2)	102(8)
C(6)	−7837(12)	4600(11)	711(2)	91(7)
O(7)	−7278(7)	3053(7)	384(1)	79(4)
C(8)	−8250(13)	1814(13)	76(2)	105(6)
C(9)	−7631(12)	242(13)	−238(2)	92(8)
C(10)	1137(11)	7235(10)	2063(2)	66(6)
C(11)	1658(13)	9418(10)	1910(2)	59(7)
C(12)	2810(13)	10485(12)	2165(2)	94(8)
C(13)	3465(14)	9472(14)	2576(2)	98(8)
C(14)	2976(16)	7367(17)	2742(2)	99(9)
C(15)	1844(16)	6257(13)	2484(2)	87(8)
C(16)	−63(10)	5999(9)	1793(2)	64(5)
N(17)	−766(9)	6845(7)	1401(2)	70(1)
O(18)	−1777(8)	5362(7)	1166(1)	105(4)
O(19)	977(7)	10464(6)	1497(1)	86(4)

* Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor.

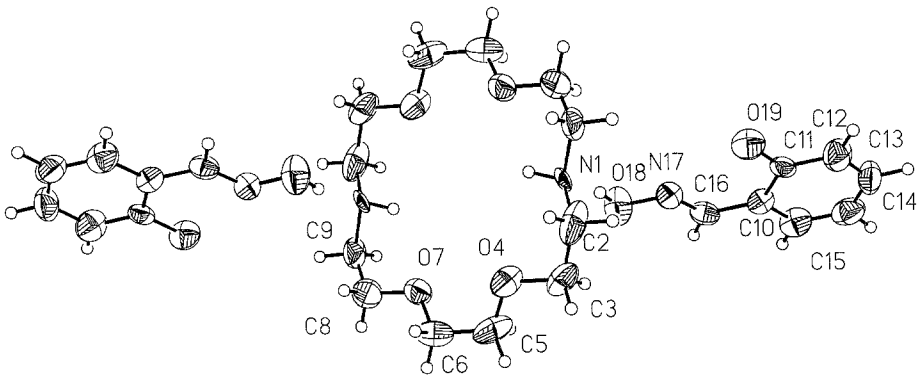

Fig. 4. Drawing of complex **25** with thermal ellipsoids drawn at the 30% probability level. H atoms are represented by spheres of arbitrary size.

Table VIII. Atomic coordinates ($\times 10^4$) and isotropic thermal parameters ($Å^2 \times 10^3$) for complex **26**

	x	*y*	*z*	*U**
N(1)	1626(6)	0	3160(6)	53(2)
C(2)	2557(6)	843(3)	3720(5)	65(2)
C(3)	1512(7)	1694(3)	3157(5)	67(2)
O(4)	1169(3)	1700(2)	1507(3)	54(1)
C(5)	123(6)	2473(3)	864(5)	63(2)
C(10)	4263(7)	0	9700(7)	50(2)
C(11)	2393(8)	0	9002(7)	57(2)
O(12)	2099(6)	0	7363(5)	95(2)

* Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor.

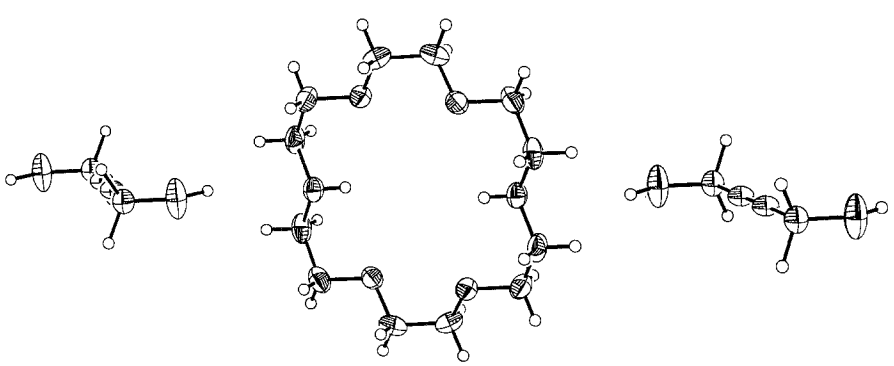

Fig. 5. Drawing of complex **26** refined in space group *Cm*. Thermal ellipsoids are drawn at the 25% probability level. The atomic positional parameters do not differ significantly from those of the *C*2/*m* refinement; however, there are differences in the values of the thermal ellipsoids. The nitrogen atom can be identified by the single proton substituent and C(2), C(3), O(4) and C(5) are numbered consecutively from N(1). The hydroxyl O(12) is attached to C(11).

Table VIII and Figure 5 is a drawing of the molecule. The drawing is that for space group *Cm* which illustrates the main difference between *Cm* and *C2/m* refinement to be anisotropic thermal motion. The oxygen atoms of the butyne moiety could not be refined as disordered pairs.

3. Results and Discussion

The three dihydroxybenzenes (**7–9**) form solid complexes with diaza-18-crown-6. Catechol (**7**) forms a 1 : 2 complex while resorcinol **8** and hydroquinone **9** form 1 : 1 complexes in which the guest molecules bridge two host molecules to form infinite polymeric chains. Extraction of a mixture of **7**, **8** and **9** with diaza-18-crown-6 leads to the isolation of the 1 : 1 complex of **9** (see Table II). There are no significant differences in the acidities of the three phenols [13] and the isolation of **9** is most likely due to the insolubility of the polymeric complex which reflects a favorable arrangement of the hydroxyl groups.

In the case of the dihydroxynapthalenes **4**, **5** and **6**, no solid complexes are isolated with diaza-18-crown-6 although the hydroxyl group orientation is equivalent to that in **7**, **8** and **9**. This may be indicative of steric interactions with the second ring which reduces host : guest interactions or affects crystal packing. The diaza-18-crown-6 complex of **1** can be precipitated selectively from mixtures of **2**, **4**, **5** and **6** which again can be rationalized in terms of the insolubility of the polymeric chain in the 1 : 1 complex. Compounds **1** and **3** cannot be separated by this procedure. Compound **2** forms a 2 : 3 host : guest complex and the solubility is expected to be greater than that of the 1 : 1 complexes.

Compounds **15** and **16** form 1 : 2 complexes with diaza-18-crown-6. The 2,4-dinitrophenol **15** (pk_a 4.09) is more acidic than the 2-nitrophenol **16** (pk_a 7.21) [13], and **15** is more effective in competing for the binding sites of diaza-18-crown-6 than **16**. The complex of **15** can be isolated by precipitation from a mixture of **15** and **16** upon addition of diaza-18-crown-6.

The trihydroxybenzenes **10**, **11** and **12** do not form solid complexes with diaza-18-crown-6 using the described reaction conditions.

In the crystal structures of the complexes **22–26** all diaza-18-crown-6 moieties adopt an approximate D_{3d} conformation except for that in **24**. In **24** there are two consecutive *gauche* interactions C(3)O(4)C(5)C(6) = 66.0(2)° and O(4)C(5)C(6)O(7) = 55.2(3)° and a short transannular interaction, H(3a)···H(6a) = 2.16(3) Å. This conformation results from a maximization of hydrogen bonding in the crystal. The conformation in **24** is calculated to be about 12 kJ/mol more stable than that of the D_{3d} conformer [14]. For all adducts interactions between amine or hydroxyl hydrogen atoms of the guests always involve the nitrogen atoms of the host. Possible hydrogen-bond like interactions are listed in Table IX.

2 : 1 *p*-Nitrophenol (**17**) : Diaza-18-crown-6, **22**. The phenyl ring and attached atoms are planar (rmsd = 0.01 Å) with the nitro group twisted out of the plane by 4.1(1)°. The phenyl ring forms an angle of 57.4(2)° with the mean plane of the crown acceptor atoms. There is a hydrogen bond between the phenolic oxygen and the nitrogen atom of the crown, O(16)···N(1) = 2.647(3) Å, O(16)—N(16)···N(1) = 167.5(5)°.

2 : 1 2,4-Dinitroaniline (**18**) : Diaza-18-crown-6, **23**. The phenyl ring and attached atoms are planar (rmsd = 0.005 Å) with the two nitro groups twisted out of the plane by 5.4(2)° and 4.8(2)°. The phenyl ring is perpendicular (89.5(2)°) to the mean plane of the host acceptor atoms. There is a hydrogen bond between the guest amine and the nitrogen of the crown, N(10)···N(1′) = 3.009(2) Å, N(10)—H(10b)···N(1′) = 172.7(3)°. There is also a

Table IX. Hydrogen bonding

Complex		
22	O(16)—H(16) = 0.92(2) Å	H(16)···N(1) = 1.74(2) Å
	O(16)···N(1) = 2.647(3) Å	O(16)—H(16)···N(1) = 167.5(5)°
23	N(10)—H(10b) = 0.87(2) Å	H(10b)···N(1′) = 2.14(2) Å
	N(1′)···N(10) = 3.009(2) Å	N(10)—H(10b)···N(1′) = 172.7(3)°
	N(10)—H(10a) = 0.76(2) Å	H(10a)···O(17) = 2.11(2) Å
	N(10)···O(17) = 2.109(2) Å	N(10)—H(10a)···O(17) = 130.0(3)°
24	N(14)—H(14) = 0.96(2) Å	H(14)···N(1) = 1.91(2) Å
	N(14)···N(1) = 2.808(2) Å	N(14)—H(14)···N(1) = 155.6(4)°
	N(1′)—H(1′) = .78(2) Å	H(1′)···O(16) = 2.13(2) Å
	N(1′)···O(16) = 2.813 Å	N(1′)—H(1′)···O(16) = 147.0(8)
	N(10) $(-x, -y, 2-z)$	
	N(10)—H(10) = 0.96 Å	H(10)···O(17) = 2.02 Å
	N(10)···O(17) = 2.975(2) Å	N(10)—H(10)···O(17) = 173.7(8)°
25	O(18)—H(18) = .92(6) Å	H(18)···N(1) = 1.77(6) Å
	O(18)···N(1) = 2.682(9) Å	O(18)—H(18)···N(1) = 169(1)
26	O(12)—H(12) = 1.03(8) Å	H(12)···N(1) = 2.90(8) Å
	O(12)···N(1) = 3.625(6) Å	O(12)—H(12)···N(1) = 129(2)°

short intramolecular interaction between the other amine hydrogen and an oxygen of an adjacent nitro group.

2 : 1 5,5-Diethylbarbituric Acid (**19**) : Diaza-18-crown-6, **24**. The six-membered heterocyclic ring is planar (rmsd = 0.04 Å) with the carbonyl oxygen atoms lying out of the plane by 0.09 to 0.13 Å. Diethylbarbituric acid **19** crystallizes in several polymorphs and X-ray [15] and neutron [16] diffraction studies of the pure compound have been reported. In the pure crystal there is a slight lengthening of the C—O bonds adjacent to the diethyl substituents due to hydrogen bonding and a subsequent decrease in the adjacent C—N bonds due to increased conjugative effects. The guest in **24** is involved in an extensive hydrogen bond network. N(14) acts as a proton donor to the crown nitrogen atom N(1) while N(1′) acts as a proton donor in forming a hydrogen bond to O(16). Adjacent 2 : 1 guest : host units link together by the formation of pairs of hydrogen bonds between N(10) and O(17) of one molecule with O(17) and N(10) of another. These interactions probably account for the deviation of the diaza-18-crown-6 from the normal D_{3d} conformation. There are significant bond distance differences between the guest in **24** and the 5,5-diethylbarbituric acid molecules in the pure crystal. In **24** the two carbonyls C(13)—O(18) and C(15)—O(16) are statistically longer than in the pure crystal while C(11)—O(17) is statistically equivalent. The two C—N bonds involving N(14) are statistically shorter indicating greater delocalization in this part of the molecule. The heterocyclic six-membered ring makes an angle of 84.0(3)° with the mean plane of the crown acceptor atoms. The crown acceptor atoms deviated from the mean plane by 0.12 to 0.16 Å (approximately 0.23 Å in the D_{3d} conformation).

2 : 1 Salicylaldoxime (**20**) : Diaza-18-crown-6, **25**. The phenyl ring is planar (rmsd = 0.006 Å) and forms an angle of 5.7(6)° with the plane formed by C(10)C(16)N(17)O(18). The phenyl ring makes an angle of 67.1(8)° with the mean plane of the crown acceptor atoms. The proton of the phenolic oxygen could not be located in difference maps although weak electron density (<0.13 eÅ^{-3}) was found between O(19) and N(17). A hydrogen bond is formed between O(18) and N(1). The structure is composed of loosely packed 2 : 1 units with intermolecular contacts primarily through the

salicylaldoxime moieties. The diaza nitrogen atoms are pinned by hydrogen bonding to the aldomine units; however, considerable flexibility exists in the remainder of the macrocycle and relatively large anisotropic thermal motions are observed. The observed and calculated densities are low compared with those of **22**, **23** and **24** indicating a relatively open, poorly packed structure. The largest residual electron density of 0.13 $eÅ^{-3}$ implies that any trapped solvent molecules must be highly mobile if present. Use of a smaller solvent molecule or a molecule more closely approximating the shape of the packing cavities may result in stabilization of the structure.

1 : 1 1,4-Dihydroxybut-2-yne : Diaza-18-crown-6, **26**. The packing of long linear molecules and short cylinders is not efficient, and it is surprising that the material can be crystallized. The calculated density again is quite low; however, the observed density is probably larger (Table III) which may indicate the trapping of solvent or its participation in the complexation. The structure consists of infinite chains of alternating host : guest molecules. The O···N separation of 3.625(5) Å is too long for hydrogen bonding or stabilization of the complex; however, difference maps indicate a diffuse electron density in the region between the crown atom N(1) and the hydroxyl group. Although no solvent peaks could be refined, disordered or mobile solvent molecules may serve as a bridge between guest and host. This has been observed in other crown host : guest complexes [5]. The loss of disordered solvent would be consistent with crystal instability during data collection. Variable solvent content would also explain the difficulties encountered in obtaining a consistent density measurement.

4. Conclusions

Diaza-18-crown-6 can be used to selectively precipitate isomeric or related aromatic hydroxy compounds if guests differ significantly in acid strength, have an optimum orientation of acceptor groups or the resulting complexes have low solubilities. In general, polymeric 1 : 1 complexes are less soluble than 2 : 1 monomeric complexes. This is true only if the host : guest interaction is strong enough to maintain a polymeric structure in solution and/or packing is efficient in the solid state. Molecules such as 4,4′-dihydroxybiphenyl, **13**, might be expected to form as strong a host : guest complex in solution as 2,6-dihydroxynaphthalene **1**; however, no crystalline complex was obtained with **13**. The packing of long linear molecules between crown ether moieties results in large void volumes and a stable structure cannot be obtained easily without solvent participation. In the crystallization of 1,4-dihydroxybutyne, **21**, with diaza-18-crown-6 solvent must play an important role. A mobile solvent environment in the void between the large crown molecules probably reflects the structure in solution. Recrystallization of **26** with solvent molecules of varying size and geometric requirements may lead to a better defined crystalline structure.

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